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Attached please find the certified copy of the foreign application from which priority is claimed for this case:

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Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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R C van Dijk

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Inspection method and device manufacturing method

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Inspection Method and Device Manufacturing Method

The present invention relates to methods of inspection useable in the manufacture of devices by lithographic techniques and to methods of manufacturing devices using lithographic techniques.

In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

The measurement and inspection step after development of the resist, referred to as in-line because it is carried out in the normal course of processing production wafers, serves two purposes. Firstly, it is desirable to detect any target areas where the pattern in the developed resist is faulty. If a sufficient number of dies are faulty, the wafer can be stripped of the patterned resist and re-exposed, hopefully correctly, rather than making the fault permanent by carrying out a process step, e.g. an etch, with a faulty

pattern. Secondly, the measurements may allow errors in the lithographic apparatus, e.g. in illumination settings or exposure times, to be detected and corrected for subsequent exposures. However, many errors in the lithographic apparatus cannot easily be detected or quantified from the patterns printed in exposures. Detection of a fault does not always lead directly to its cause. Thus, a variety of off-line procedures for detecting and measuring errors in the lithographic apparatus are known. These may involve replacing the substrate with a measuring device or carrying out exposures of special test patterns, e.g. at a variety of different machine settings. Such off-line techniques take time, often a considerable amount, during which the apparatus cannot be used for production exposures. Therefore, in-line techniques, that is ones which can be carried out using or at the same time as production exposures, for detecting and measuring errors in the lithographic apparatus are preferred.

To measure dimensional errors, such as overlay and left-right dimensional differences caused by comatic aberration, image-based tools, such as box-in-box (or frame-in-frame) for overlay and scanning electron microscopes (SEM) to measure critical dimensions (CD) for coma, are used at present. These techniques, as well as being off-line, have the disadvantage that they make localized measurements which do not necessarily accurately reflect the projection system or process behavior over the full die or target area.

One in-line technique used in device manufacturing for measurements of linewidth, pitch and critical dimension (CD) is known as "scatterometry". Methods of scatterometry are described in Raymond *et al* "Multiparameter Grating Metrology Using Optical Scatterometry", J. Vac. Sci. Tech. B, Vol.15 no.2 361-368 1997 and Niu *et al* "Specular Spectroscopic Scatterometry in DUV Lithography", SPIE, Vol. 3677, 1999. In scatterometry, white light is reflected by periodic structures in the developed resist and the resulting reflection spectrum at a given angle detected. The structure giving rise to the reflection spectrum is reconstructed, e.g. using Rigorous Coupled-Wave Analysis (RCWA) or by comparison to a library of spectra derived by simulation. However, the reconstruction of the structure is computationally very intensive and the technique can suffer from low sensitivity and poor repeatability.

It is an object of the present invention to provide an in-line method of making measurements during manufacture of devices using lithographic techniques that has improved accuracy, sensitivity and/or repeatability.

This and other objects are achieved according to the invention in an inspection method comprising the steps of:

using a lithographic apparatus to print onto a substrate a test pattern having first and second components, and first and second reference patterns corresponding respectively to said first and second components;

using a scatterometer to measure first, second and third reflection spectra of said test pattern and said first and second reference patterns; and

deriving from said first, second and third reflection spectra information indicative of a parameter of said test pattern on said substrate.

By this method, a rapid, accurate and repeatable measurement of a parameter of the test pattern as printed on the substrate can be made. The test and reference patterns can be printed in the course of production exposures, for example in a scribe lane or edge die or other unused area of the substrate, without requiring significant additional time. The reflection spectra can be measured by the scatterometer equally quickly and without delaying the production line. The measurement method of the invention can therefore be used in-line, as a qualification or calibration tool.

The addition of the reference patterns improves the sensitivity as compared to scatterometry techniques using a single test pattern and can simplify the process of deriving the desired information from the scatterometry data. In some cases, reconstruction of the reference patterns is simpler than reconstruction of the two-component test pattern and is performed first. The results of the reconstruction of the reference pattern are then used to simplify reconstruction of the test pattern. In other cases, the desired information can be obtained directly from comparison of the different spectra, without the necessity for reconstruction of the test pattern.

In one preferred embodiment of the invention, the test pattern comprises first and second alignment markers printed on top of one another in first and second process layers. The reference patterns comprise corresponding reference alignment markers printed in the first and second process layers respectively, but not overlaid. This embodiment enables an accurate and sensitive measurement of overlay by using the

scatterometry signals from the reference alignment marks to enhance the scatterometry signal from the test pattern prior to processing to determine the overlay error. The scatterometry signal from the test pattern is affected by distortions of the alignment markers due to the process steps used to form them and carried out in between and by the process layers between the layers carrying the alignment markers, as well as by the overlay error which it is desired to measure. The reference patterns enable these effects to be separated from the effect of overlay.

In another preferred embodiment of the invention, the test pattern comprises a two-bar grating pattern having an inner pitch and an outer pitch. The first and second reference patterns comprise respectively a single bar grating having a pitch equal to the inner pitch and a single bar grating having a pitch equal to the outer pitch. The scatterometry signals from the reference gratings contain information as to the form of the two components of the two-bar grating and enable the asymmetry information that is indicative of coma to be isolated from the scatterometry response of the test pattern.

Preferably the scatterometry step is carried out on the pattern in developed resist although if there is sufficient contrast in the latent resist image, the scatterometry step may be carried out before development. Because the aberration is detected before a process step is carried out, if the aberration is severe enough to result in a defective device, the resist can be stripped and the substrate put back into the process for re-imaging.

Preferably, the scatterometry step(s) is (are) carried out using normal incidence, white light scatterometry.

According to a further aspect of the invention there is provided a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

characterized in that:

said pattern comprises a pattern representing a process layer and a test pattern

having first and second components, and first and second reference patterns corresponding respectively to said first and second components; and by the further steps of:

using a scatterometer to measure first, second and third reflection spectra of said test pattern and said first and second reference patterns; and

deriving from said first, second and third reflection spectra information indicative of a parameter of said test pattern on said substrate.

Preferably, the test pattern is printed in an area adjacent the pattern of the production layer, such as a scribe lane. In this way, no unnecessary space is taken up on the substrate and a maximum area remains for production of devices.

In a preferred embodiment of this aspect of the invention, said information indicative of a parameter is used to adjust a parameter of the lithographic apparatus or process after which a further substrate is provided and said steps of providing a projection beam, using patterning means and projecting the patterned beam, are repeated. In this way, the results of scatterometry measurements taken on one substrate can be used to adjust the lithographic apparatus or process so that subsequent exposures are improved.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (*e.g.* with a wavelength of 365, 248, 193, 157 or 126 nm) and EUV (extreme ultra-violet radiation, *e.g.* having a wavelength in the range 5-20 nm), as well as particle beams, such as ion beams or electron beams.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus that may be used in the performance methods according to the invention;

Figure 2 is a flow diagram of a lithographic process according to an embodiment of the invention;

Figure 3 depicts a scatterometer useable in methods according to the present invention;

Figures 4 to 6 depict a test pattern and first and second reference patterns used in a first method according to the present invention;

Figure 7 depicts a raw overlay signal and an overlay signal enhanced according to the first method according to the present invention; and

Figures 8 to 10 depict a test pattern and first and second reference patterns used in a second method according to the present invention.

In the Figures, corresponding reference symbols indicate corresponding parts.

Lithographic Projection Apparatus

Figure 1 schematically depicts a lithographic projection apparatus useable in methods according to the invention. The apparatus comprises:

a radiation system Ex, IL, for supplying a projection beam PB of radiation (*e.g.* DUV radiation), which in this particular case also comprises a radiation source LA;

a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;

a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (*e.g.* a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;

a projection system ("lens") PL (*e.g.* a refractive lens system) for imaging an irradiated portion of the mask MA onto a target portion C (*e.g.* comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (*e.g.* has a transmissive mask). However, in general, it may also be of a reflective type, for example (*e.g.* with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

The source LA (*e.g.* an excimer laser) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1.

However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;

2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

Figure 2 is a flow diagram of a lithographic process of which the present invention may form part. Prior to the exposure step S4, which may be carried out using a lithographic apparatus such as described above with relation to Figure 1, a substrate, *e.g.* a silicon wafer, undergoes a priming step S1, spin coating step S2 to coat it with a layer of resist and a soft bake S3 to remove solvents from the resist. After exposure, the wafer undergoes a post-exposure bake S5, a development step S6 during which the exposed or unexposed resist (depending on whether the resist is positive or negative) is removed and a hard bake S7, prior to an inspection step S8. The inspection step S8 includes various different measurements and inspections and according to the invention includes a scatterometry step described further below. If the wafer passes inspection, a process step S9 is carried out. This may involve etching the areas of the substrate not covered by resist, deposition of a product layer, metallization, ion implantation, etc. After the process step S9 the remaining resist is stripped S10 and a final inspection S11 carried out before the process resumes for another layer. In case a substrate fails an inspection at S8, it may be directed directly to a stripping step S10 and another attempt to print the same process layer made.

In the inspection step S8, a scatterometer such as depicted in Figure 3 may be used. Other inspections and/or measurements may also be made using other tools. The scatterometer 10 comprises a broadband (white light) radiation source 11 which directs radiation via a beamsplitter 12 onto a test structure TS on the wafer W. The reflected radiation is passed to a spectrometer 13 which measures a spectrum (intensity as a function of wavelength) of the specular reflected radiation. From this data, the structure giving rise to the detected spectrum may be reconstructed, *e.g.* by Rigorous Coupled Wave Analysis and non-linear regression or by comparison with a library of simulated spectra. In general, for the reconstruction the general form of the structure is known and some parameters are assumed from knowledge of the process by which the structure was made, leaving only a few parameters of the structure to be determined from the scatterometry data.

As illustrated, the scatterometer is a normal-incidence scatterometer. However the same principle may be applied using inclined incidence scatterometry. Variants of scatterometry in which the reflection at a range of angles of a single wavelength, rather than the reflection at a single angle of a range of wavelengths, is measured may also be used.

Embodiment 1

According to a first method of the invention, which is used to measure overlay, the test structure printed on the substrate W comprises a first mark G1 printed in an upper process layer TL and a second mark G2 printed in a lower process layer BL. The marks G1 and G2 may take any convenient form, such as gratings, checkerboards, boxes, frames, chevrons, etc.. The form of the marks is chosen for ease of reconstruction, in particular the use of gratings allows rapid reconstruction techniques to be used. The mark type can also be chosen to improve sensitivity. The two marks G1 and G2 should be, if printed perfectly and unaffected by subsequent processes, identical and in the absence of overlay error, exactly aligned. When the test pattern comprising marks G1, G2 is illuminated with normally instant polarized light the reflected TE, TM or phase signal contains information about the relative position of the two gratings. However, due to internal reflections in the intervening process layers IL between the upper and lower layers TL, BL containing the gratings G1, G2 and interference, the amplitude of the total reflected signal containing overlay information is very weak and has a low signal-to-noise ratio.

Further noise is introduced by distortions in the marks G1, G2 during printing and, in the case of the lower mark G2, by the processes that have being carried out since it was printed.

According to the present invention, to improve measurement of overlay, two reference marks RG1, RG2 are printed at the same time as the two parts G1, G2 of the test pattern. Reference pattern RG1 is provided in the top layer TL and corresponds to the first mark G1. Reference pattern RG2 is provided in the bottom layer BL and corresponds to the second alignment mark G2. The reference patterns RG1, RG2 are printed close to but spaced apart from each other and the test pattern comprising alignment marks G1, G2. The reference markers RG1, RG2 and the test pattern should be close enough together that they will be affected in the same way by any distortions in the printing process or caused by subsequent process steps. At the same time, they should be sufficiently far apart that separate scatterometry measurements can be taken, without crosstalk.

When illuminated in the same way as the test pattern, the reference patterns RG1, RG2 produce scatterometry signals S2, S3 which contain information only about the respective gratings. The scatterometry signals S2, S3 can then be used to normalize the scatterometry signal S1 to provide an enhanced scatterometry signal S1-e. An example of this is shown in Figure 7 from which it can be seen that the enhanced signal S1-e has a much higher amplitude but retains the same phase position fingerprint of the original signal. The signal-to-noise ratio is effectively improved. The enhanced overlay signal is derived from three specular spectroscopic signals. The first is the "raw" overlay signal generated by the two overlying gratings. The second and third are the signal generated by the bottom and top reference gratings. The enhanced overlay signal is then derived by dividing the raw overlay signal by the signal from the top reference grating minus the signal from the bottom reference grating.

<u>Embodiment 2</u>

A grating structure used in a second method of the present invention is depicted in Figures 8 to 10. The second method of the present invention measures differential dimensional asymmetry due to comatic aberration in the lithographic apparatus, particularly the projection system PL, or process.

As shown in Figure 8, the test pattern G comprises a two-bar grating having an inner pitch P_i and an outer pitch P_o. The two reference gratings RG1', RG2' are shown in Figures 9 and 10 and comprise respectively a simple grating of pitch P_i and a simple grating of pitch P_o.

As in the first method, the test pattern G and reference patterns RG1', RG2' are illuminated identically with specular polarized light. The resulting reflectance spectra S1', S2', S3' contain information about any differential dimensional asymmetries as well as the actual forms of the gratings. The information about any differential dimensional asymmetry is contained in the reflectance spectra S1' from the dual pitch grating whilst the spectra S2', S3' contain information about the gratings themselves. As in the first method, the reflectance spectra S2', S3' are used to enhance the reflectance spectra S1' to provide a signal containing information of the dimensional asymmetry with an improved signal-to-noise ratio.

Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

CLAIMS:

1. An inspection method comprising the steps of:

using a lithographic apparatus to print onto a substrate a test pattern having first and second components, and first and second reference patterns corresponding respectively to said first and second components;

using a scatterometer to measure first, second and third reflection spectra of said test pattern and said first and second reference patterns; and

deriving from said first, second and third reflection spectra information indicative of a parameter of said test pattern on said substrate.

2. An inspection method according to claim 1 wherein said step of deriving information comprises reconstructing said first and second reference patterns using said first and second reflection spectra and using the reconstructed reference patterns to reconstruct said test pattern.

3. An inspection method according to claim 1 wherein in said step of deriving, said information is obtained directly from said reflection spectra, without reconstruction of the test pattern.

4. An inspection method according to claim 1, 2 or 3 wherein said test pattern comprises first and second alignment markers printed on top of one another in first and second process layers and said first and second reference patterns comprise corresponding reference alignment markers printed in the first and second process layers respectively, but not overlaid.

5. An inspection method according to claim 1, 2 or 3 wherein said test pattern comprises a two-bar grating pattern having an inner pitch and an outer pitch and said first and second reference patterns comprise respectively a single bar grating having a pitch equal to the inner pitch and a single bar grating having a pitch equal to the outer pitch.

6. An inspection method according to any one of the preceding claims wherein said

scatterometer is a normal incidence scatterometer.

7. A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

characterized in that:

said pattern comprises a pattern representing a process layer and a test pattern having first and second components, and first and second reference patterns corresponding respectively to said first and second components; and by the further steps of:

using a scatterometer to measure first, second and third reflection spectra of said test pattern and said first and second reference patterns; and

deriving from said first, second and third reflection spectra information indicative of a parameter of said test pattern on said substrate.

8. A device manufacturing method according to claim 7 wherein said test pattern is printed in an area adjacent the pattern of the production layer, such as a scribe lane.

9. A device manufacturing method according to claim 7 or 8 wherein said information indicative of a parameter is used to adjust a parameter of the lithographic apparatus or process after which a further substrate is provided and said steps of providing a projection beam, using patterning means and projecting the patterned beam, are repeated.

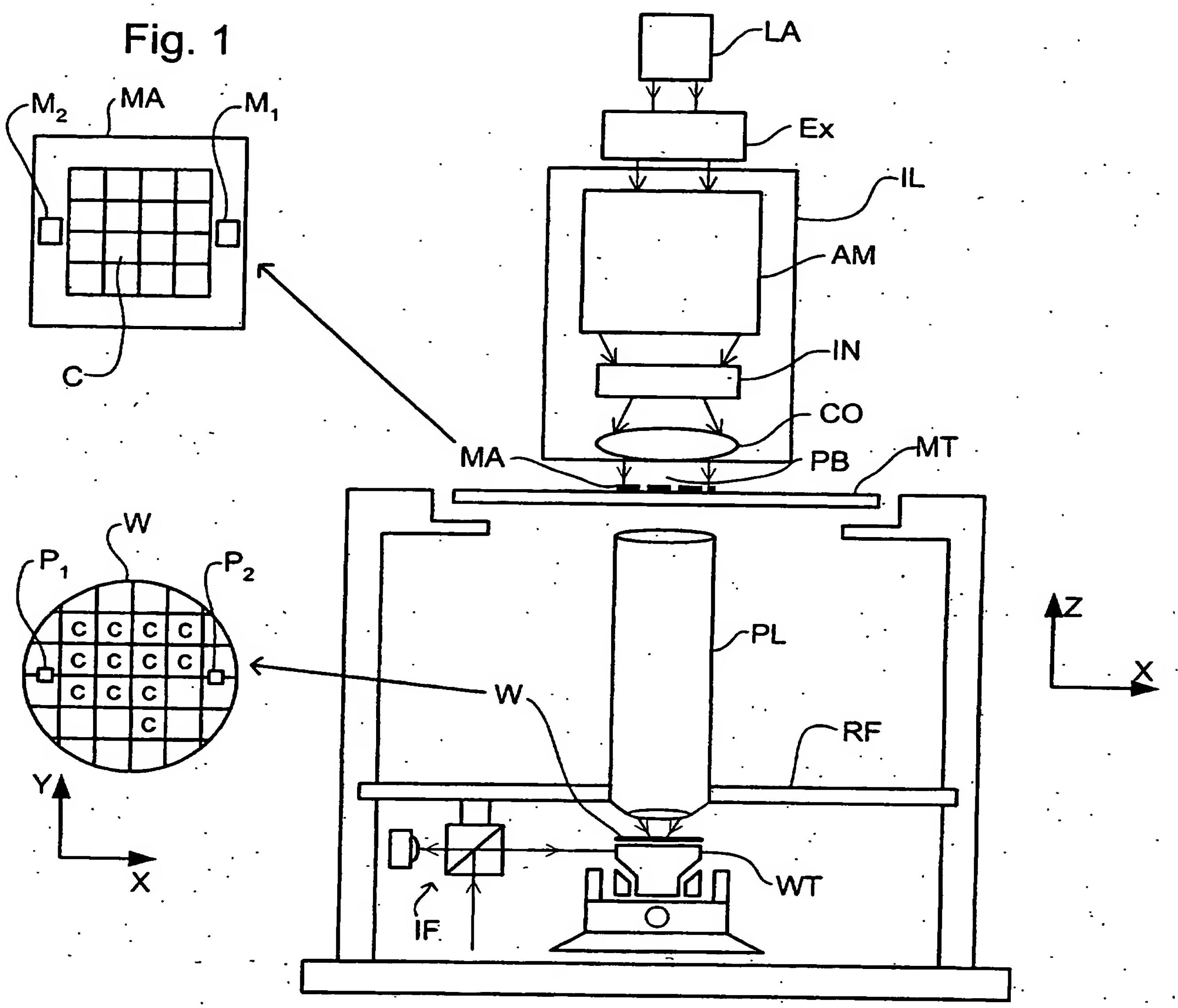
ABSTRACT

Inspection Method and Device Manufacturing Method

To enhance scatterometry measurements made from a two-component test pattern, reference patterns corresponding to each of the components of the two-component pattern are also printed. Scatterometry signals derived from the reference patterns, corresponding to the separate components of the test pattern, are used to enhance the signal from the test pattern to improve sensitivity and signal-to-noise ratios.

Fig. 4

Fig. 1



M2
MA
M1
C
W
P1
P2
c c c c
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Fig.2

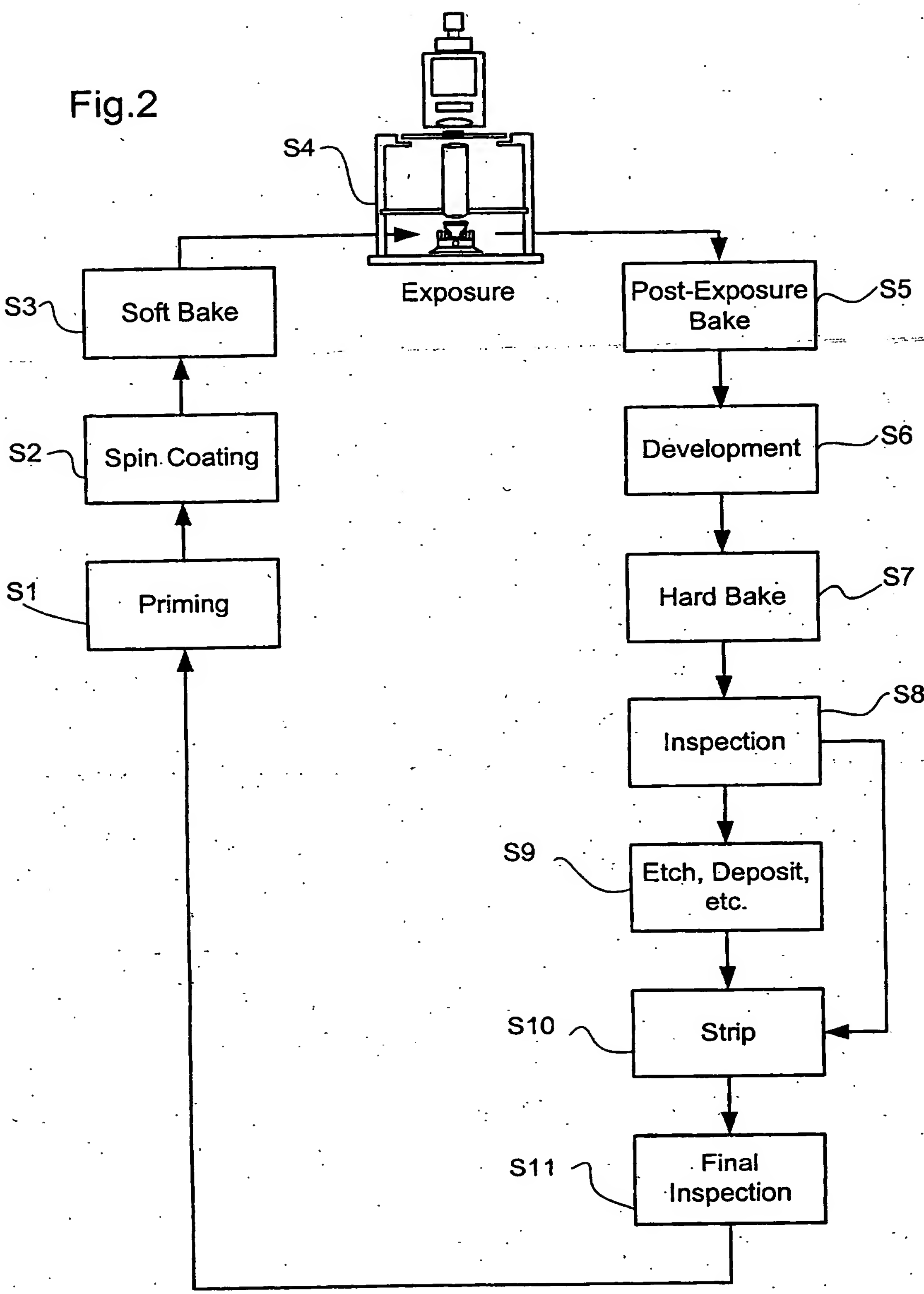
S4
Exposure
S3
Soft Bake
S2
Spin Coating
S1
Priming
Post-Exposure Bake
S5
Development
S6
Hard Bake
S7
Inspection
S8
S9
Etch, Deposit, etc.
S10
Strip
S11
Final Inspection

Fig. 3

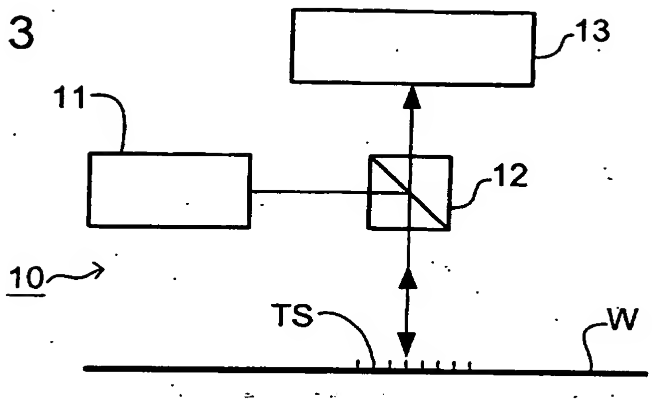

Fig. 4

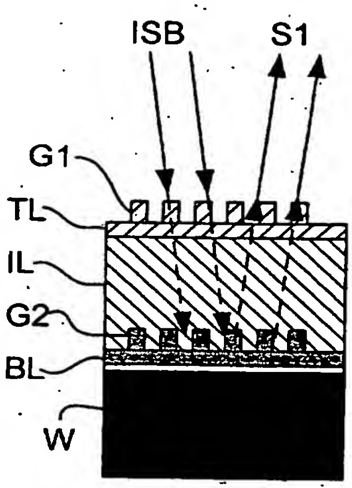

Fig. 5

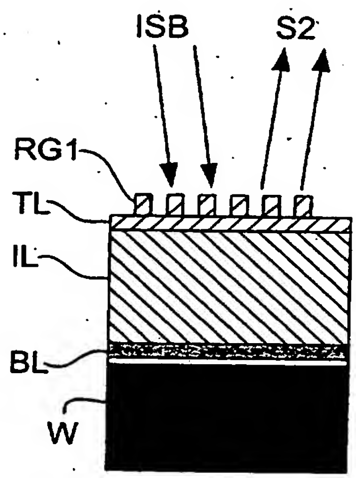

Fig. 6

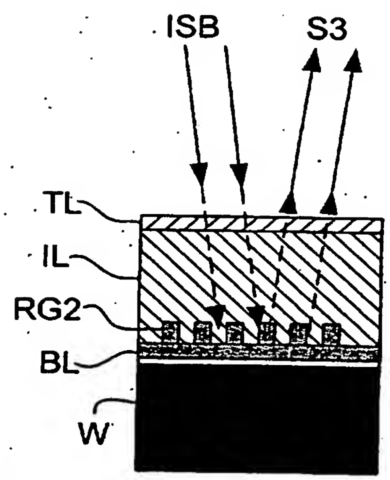

Fig. 7

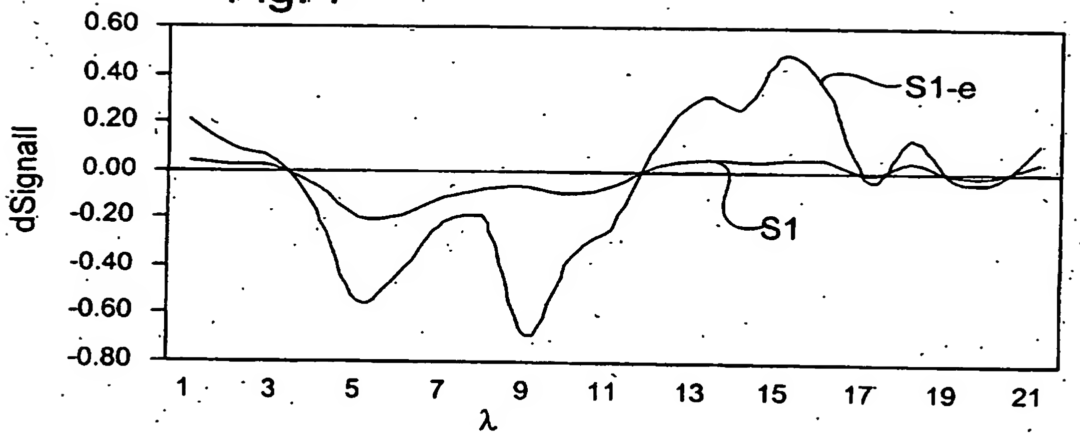

Fig. 8

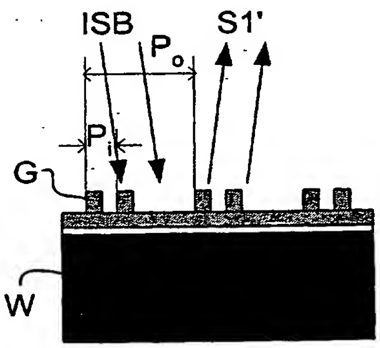

Fig. 9

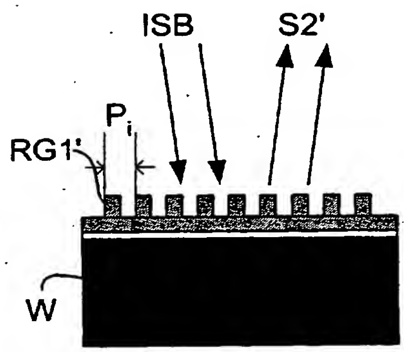

Fig.10